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(54) **HYBRID COVERLAY/WINDOW STRUCTURE
FOR FLEXIBLE DISPLAY APPLICATIONS**

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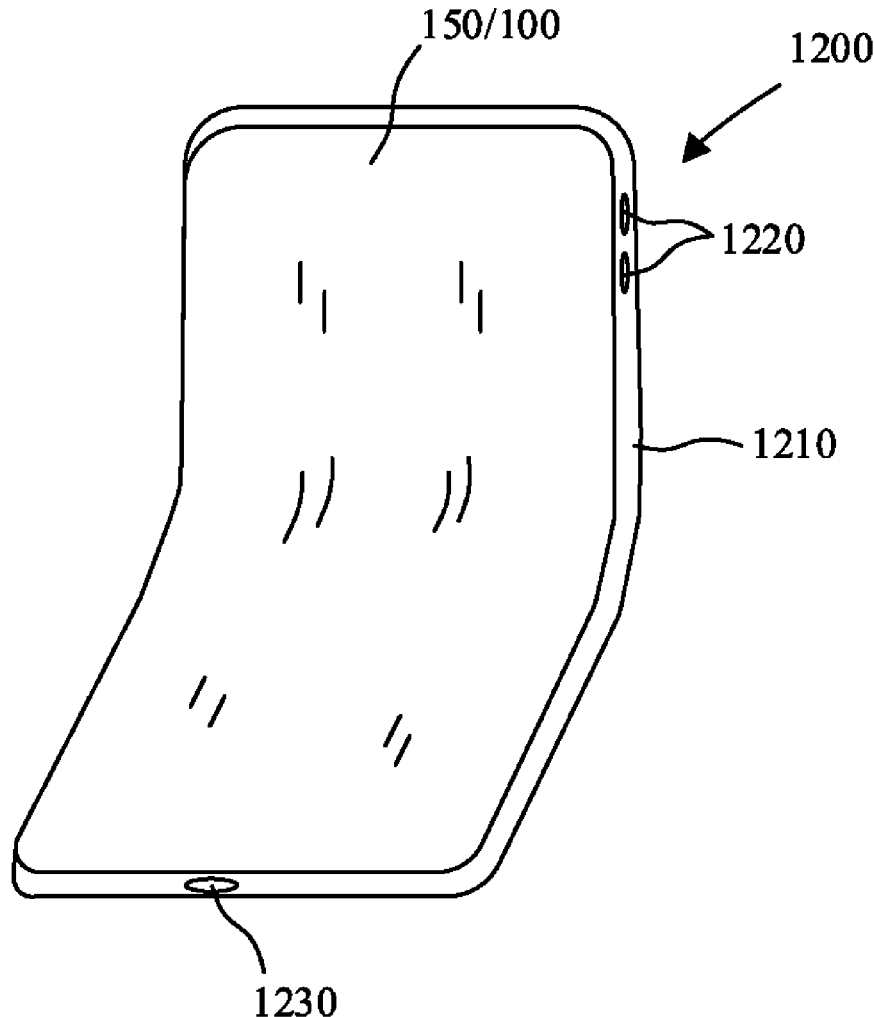
Related U.S. Application Data

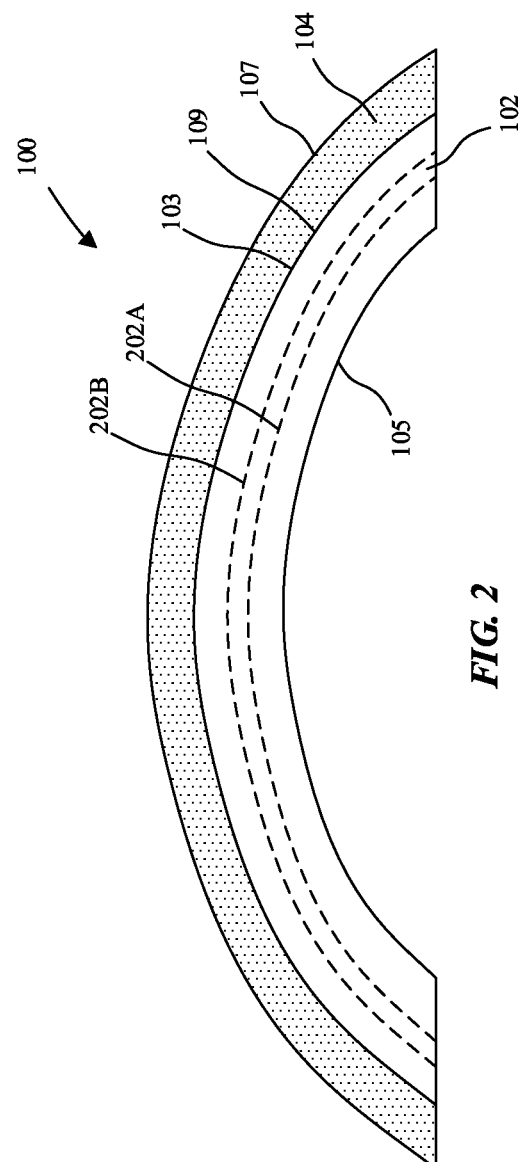
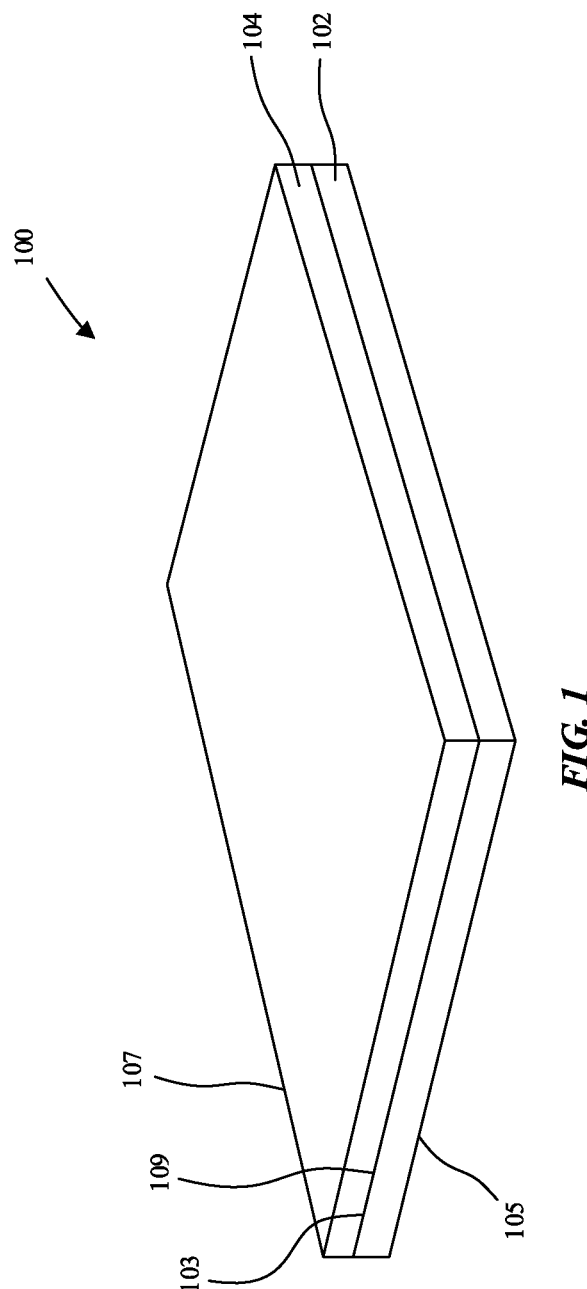
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24, 2018.

(57)

ABSTRACT

Protective cover layers for electronic devices are described. In an embodiment, an electronic device includes a display panel and a protective cover layer over the display panel. The protective cover layer includes a transparent support substrate and a hardcoat layer covering an exterior facing surface of the transparent support substrate. The display panel may be a flexible display panel and the protective cover layer may flex with the flexible display panel.





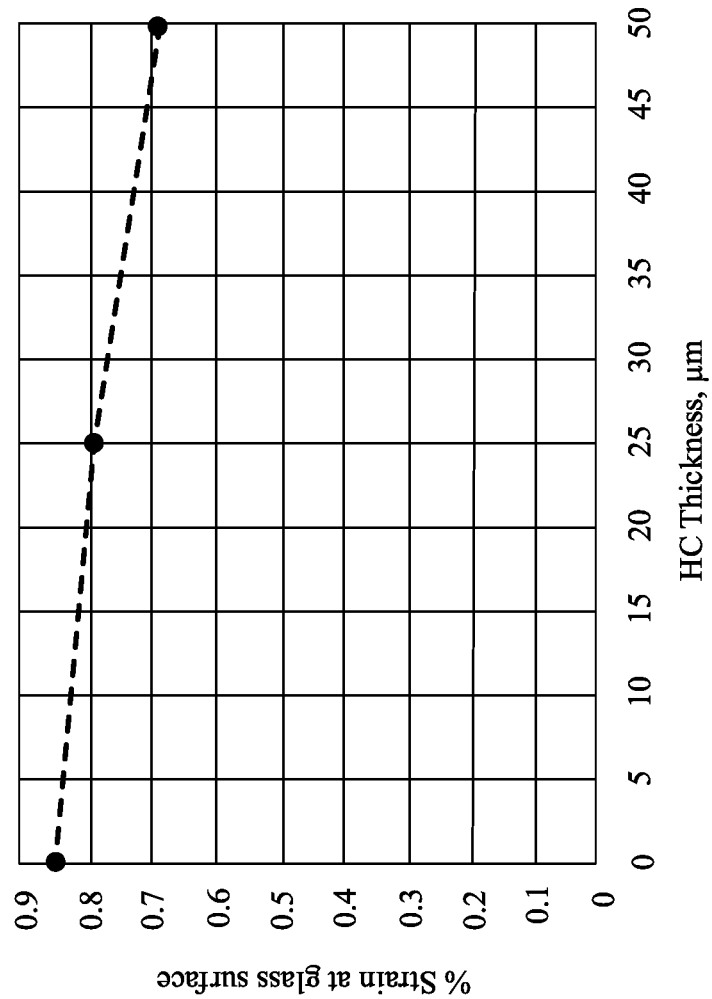


FIG. 3

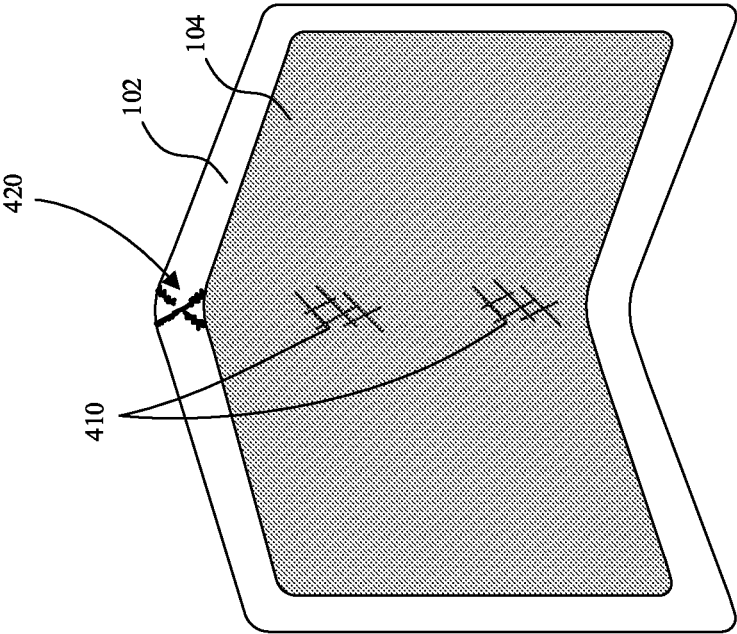


FIG. 4B

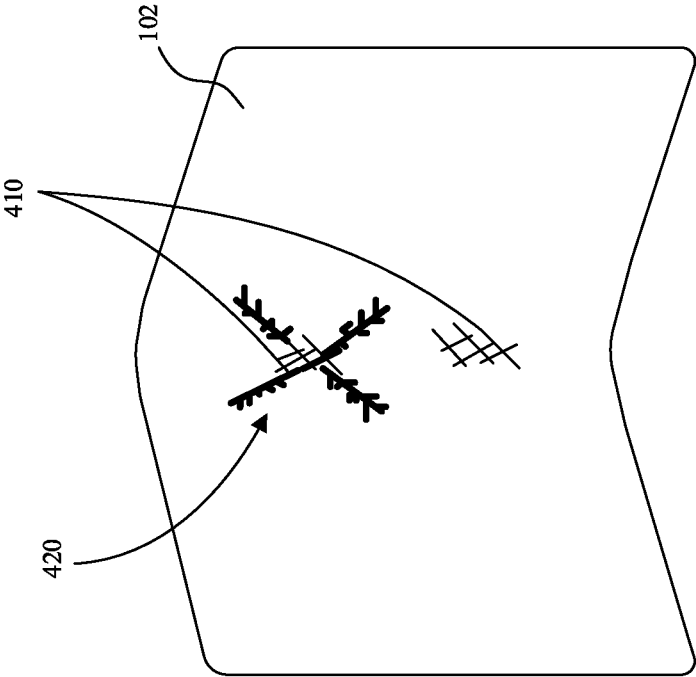


FIG. 4A

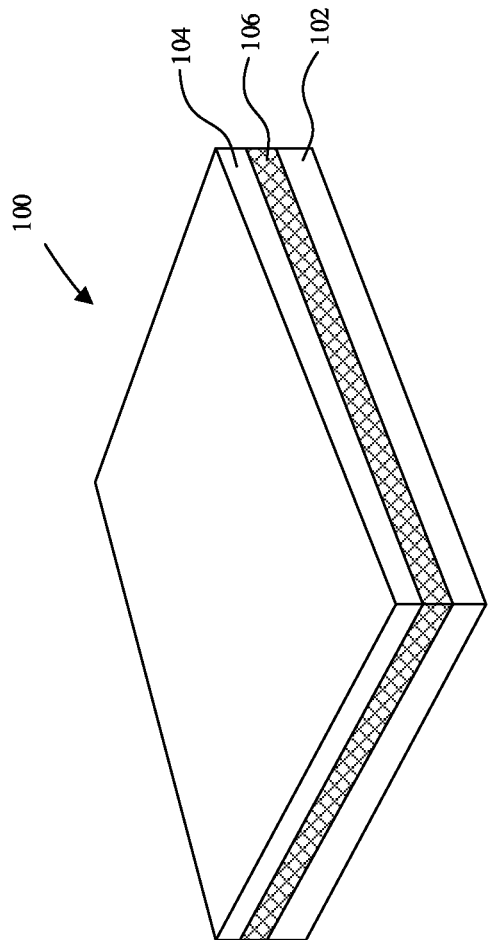


FIG. 5A

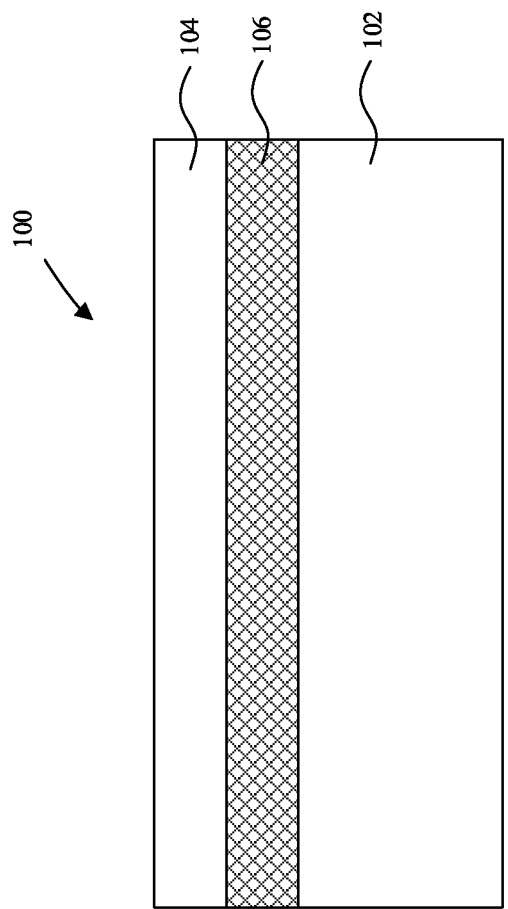


FIG. 5B

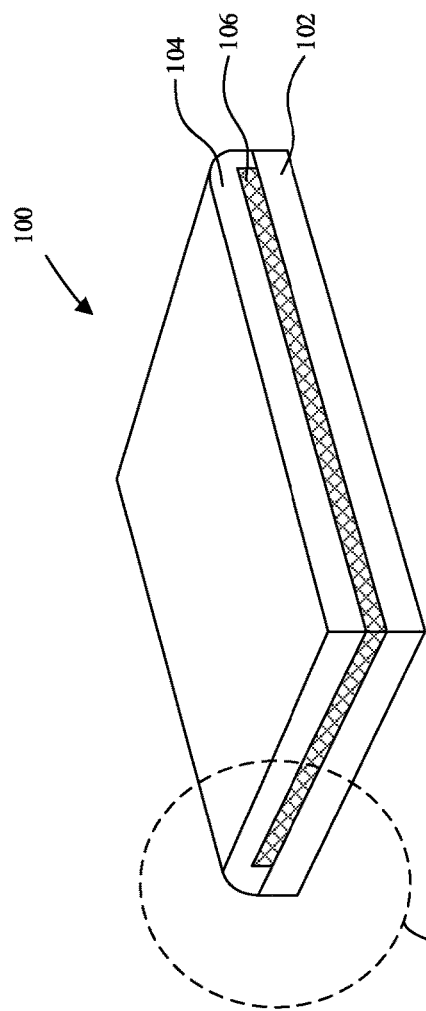


FIG. 6A

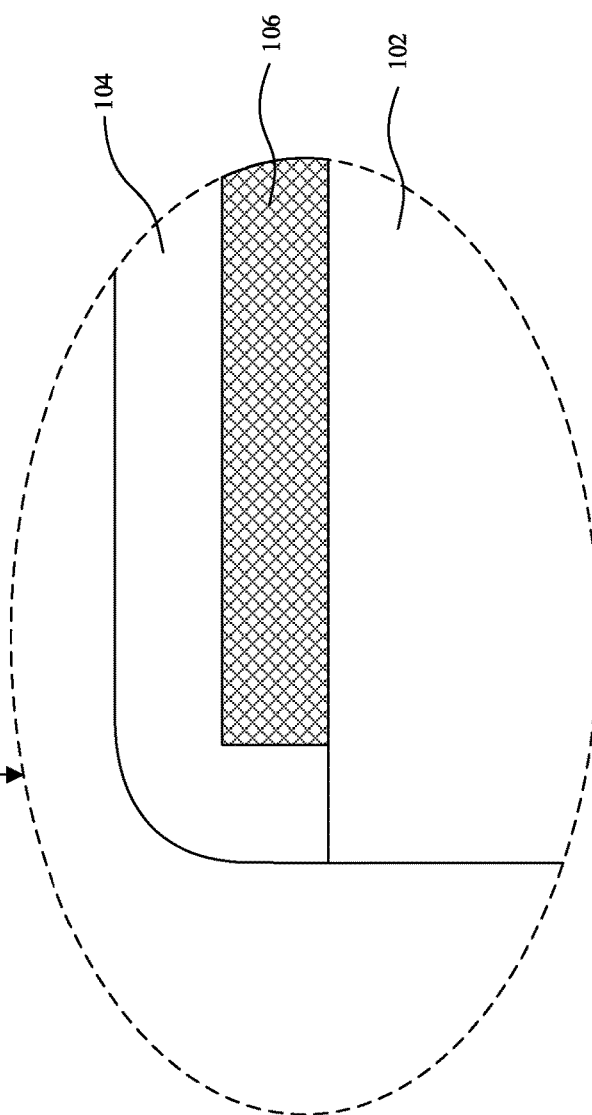


FIG. 6B

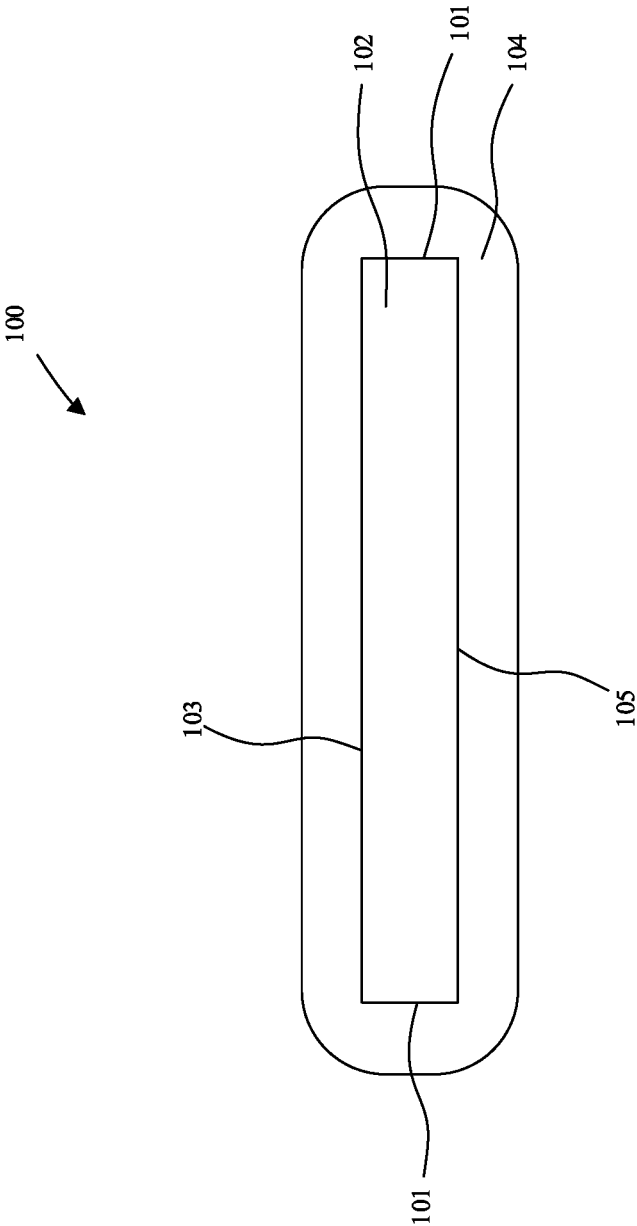


FIG. 7

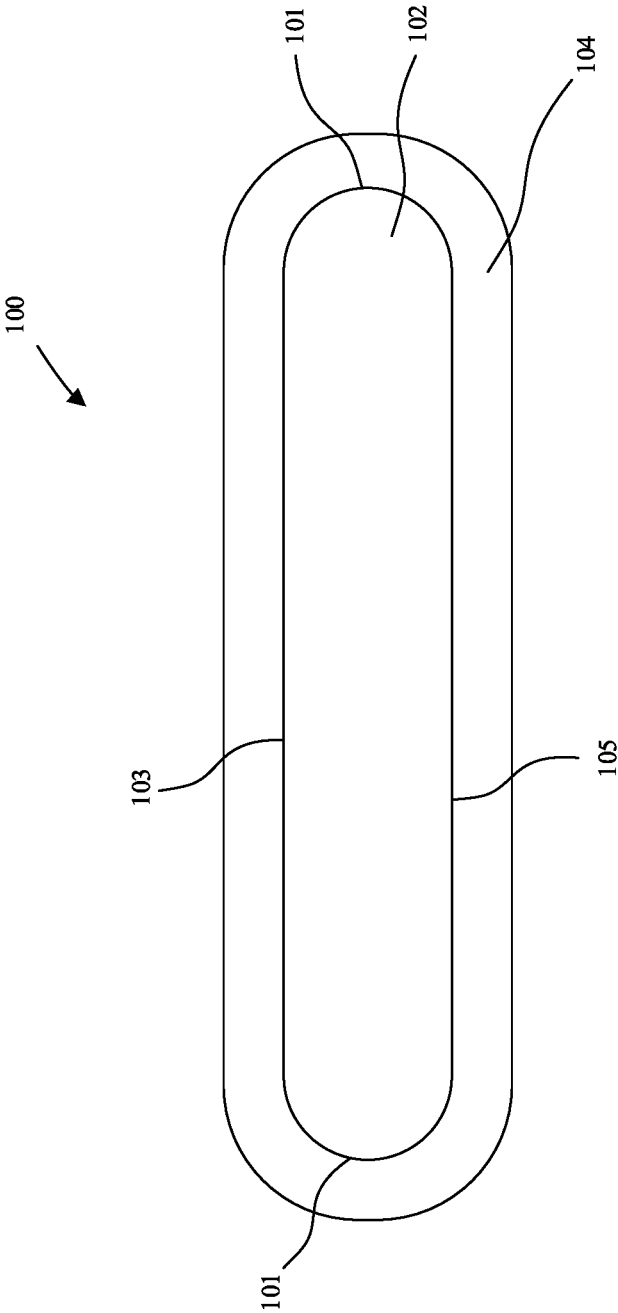


FIG. 8

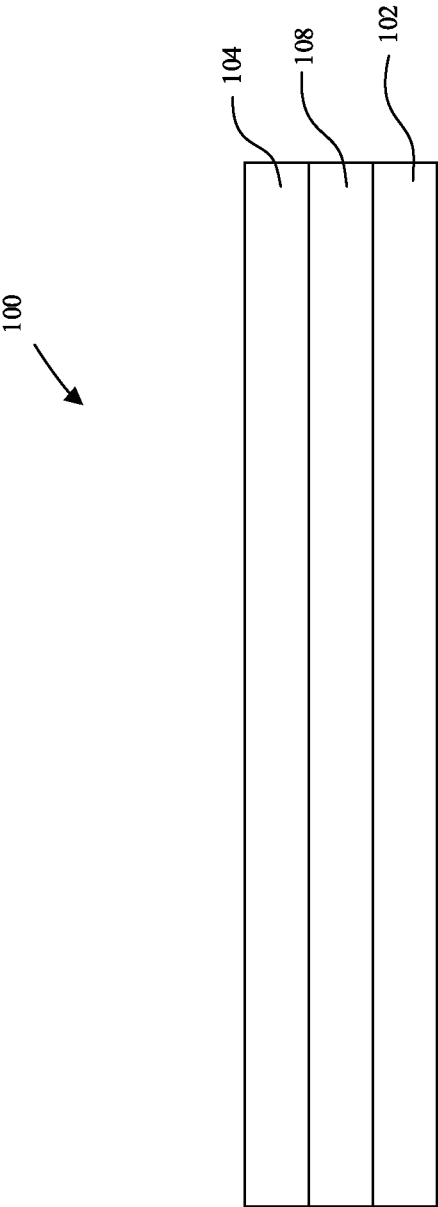


FIG. 9

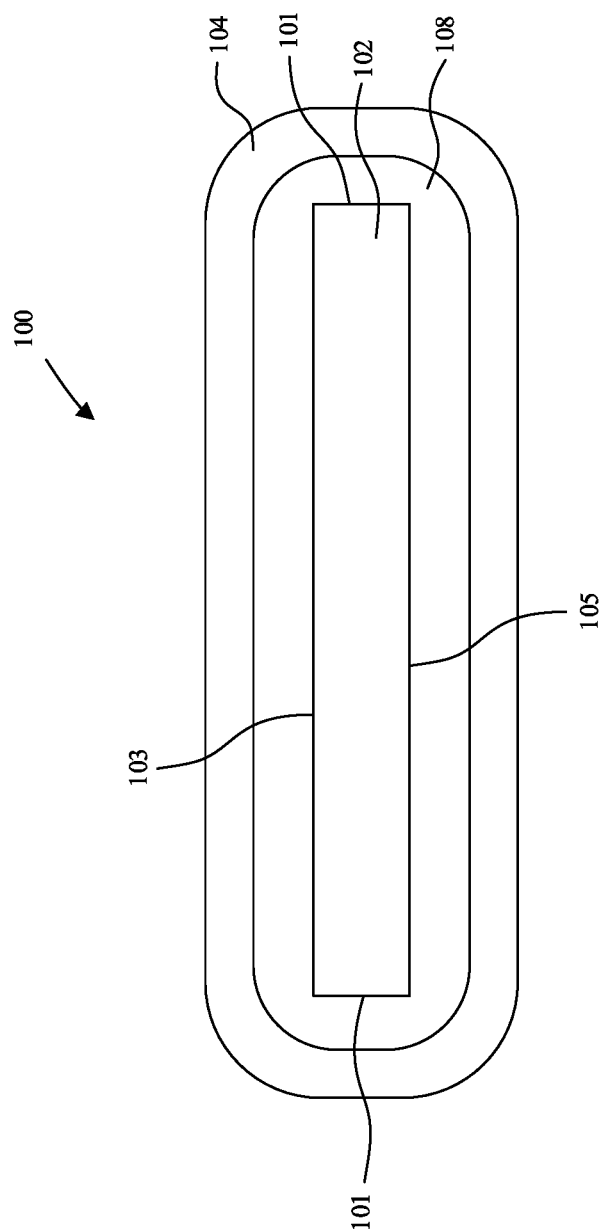


FIG. 10

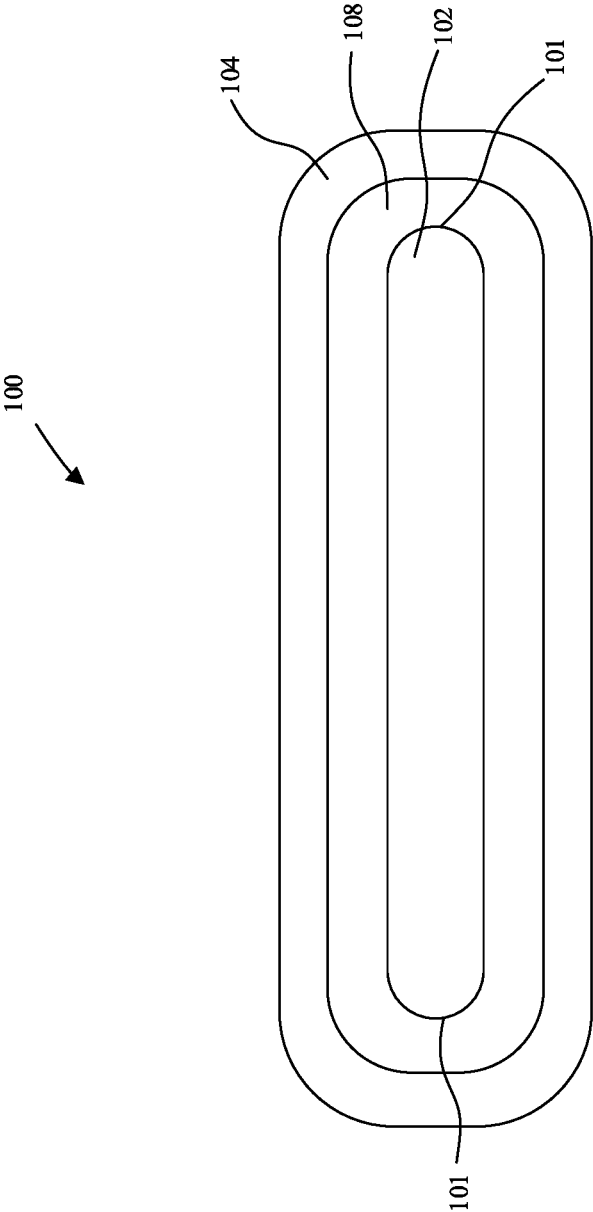


FIG. 11

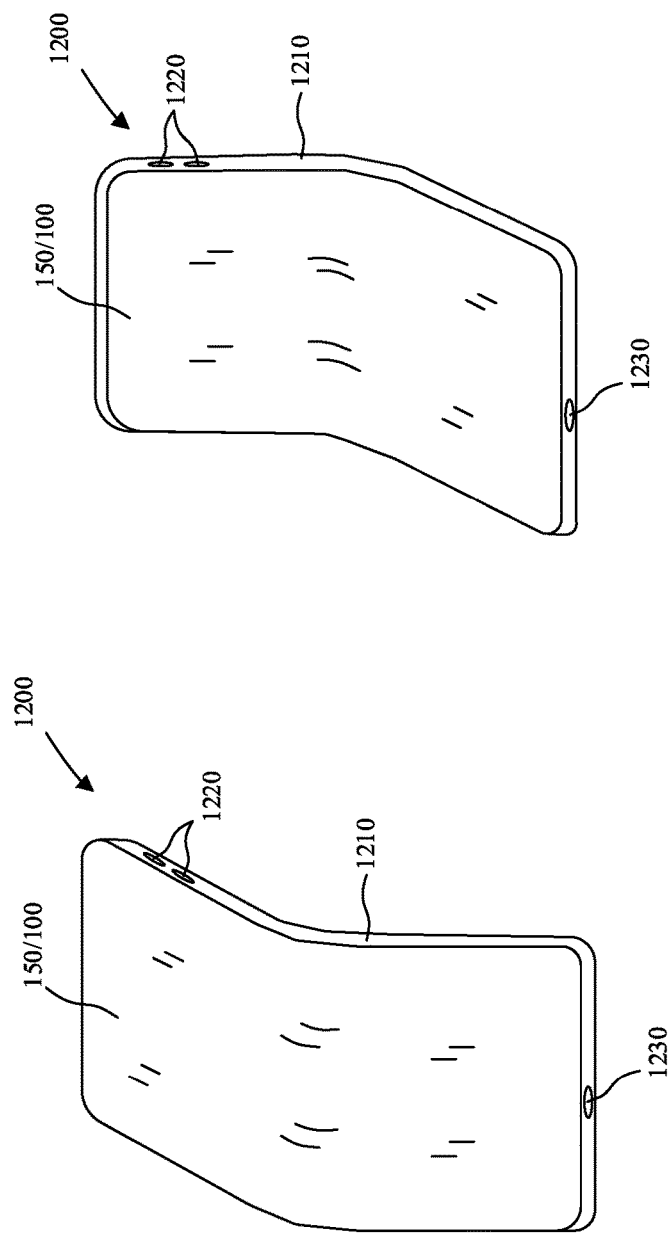


FIG. 12A

FIG. 12B

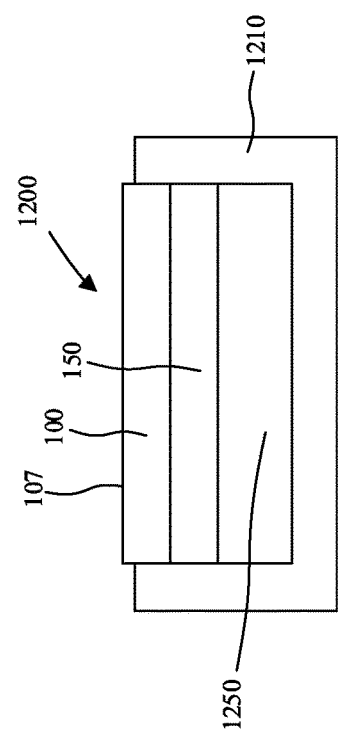


FIG. 13

HYBRID COVERLAY/WINDOW STRUCTURE FOR FLEXIBLE DISPLAY APPLICATIONS

RELATED APPLICATIONS

[0001] This application claims the benefit of priority from U.S. Provisional Patent Application Ser. No. 62/735,569 filed on Sep. 24, 2018, the full disclosure of which is incorporated herein by reference.

BACKGROUND

Field

[0002] Embodiments described herein relate to protective cover layer structures for portable electronic devices, and more particularly for flexible displays.

Background Information

[0003] Portable and wearable electronic devices commonly include a housing module that encases various components of the electronic device such as a display screen, touch screen, and protective cover layer. The protective cover layer may be a transparent plastic or glass material that provides a protective outer surface of the electronic device, and also functions as a transparent window for the display screen. Common requirements of the protective cover layer include transparency, rigidity, and scratch resistance.

SUMMARY

[0004] Electronic devices with display panels and protective cover layer structures are described. In accordance with some embodiments, the display panels and protective cover layer structures can be curved, flexible, and/or conformable. In an embodiment, an electronic device includes a display panel and a protective cover layer over the display panel. The protective cover layer may include a transparent support substrate and a hardcoat layer covering an exterior facing surface of the transparent support substrate. The hardcoat layer may optionally define an exterior surface of the electronic device.

[0005] In some embodiments, the hardcoat layer is characterized by a lower elastic modulus and lower hardness than the transparent support substrate. It is not a requirement that the hardcoat layer have a lower hardness. In some embodiments, the hardcoat layer is characterized by a lower elastic modulus and higher elongation-to-break. The hardcoat layer may be formed on a single surface or multiple surfaces of the transparent support substrate. In accordance with embodiments, the transparent support substrate may be a brittle substrate such as glass or sapphire rather than polymeric substrate. Nevertheless, the brittle substrate may be curved, flexible, and/or conformable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a schematic isometric view illustration of a protective cover layer in accordance with an embodiment.

[0007] FIG. 2 is a schematic cross-sectional side view illustration of a bent protective cover layer in accordance with an embodiment.

[0008] FIG. 3 is a plot of simulated tensile strain at the transparent support substrate surface for different hardcoat layer thicknesses in accordance with embodiments.

[0009] FIG. 4A is a schematic top view illustration of crack propagation in a scratched transparent support substrate in accordance with an embodiment.

[0010] FIG. 4B is a schematic top view illustration of crack propagation in a scratched transparent support substrate with hardcoat layer in accordance with an embodiment.

[0011] FIG. 5A is a schematic cross-sectional isometric view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment.

[0012] FIG. 5B is a schematic cross-sectional side view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment.

[0013] FIG. 6A is a schematic cross-sectional isometric view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment.

[0014] FIG. 6B is a close-up schematic cross-sectional side view illustration of the protective cover layer of FIG. 6A including an intermediate glass fiber mesh layer in accordance with an embodiment.

[0015] FIG. 7 is a schematic cross-sectional side view illustration of a protective cover layer including a hardcoat layer surrounding a transparent support substrate in accordance with an embodiment.

[0016] FIG. 8 is a schematic cross-sectional side view illustration of a protective cover layer including a hardcoat layer surrounding a transparent support substrate with tapered edges in accordance with an embodiment.

[0017] FIG. 9 is a schematic cross-sectional view illustration of a protective cover layer including an intermediate polymer adhesion layer in accordance with an embodiment.

[0018] FIG. 10 is a schematic cross-sectional side view illustration of a protective cover layer including an intermediate polymer adhesion layer and hardcoat layer surrounding a transparent support substrate in accordance with an embodiment.

[0019] FIG. 11 is a schematic cross-sectional side view illustration of a protective cover layer including an intermediate polymer layer and hardcoat layer surrounding a transparent support substrate with tapered edges in accordance with an embodiment.

[0020] FIGS. 12A-12B are schematic isometric view illustrations of an electronic device in accordance with embodiments.

[0021] FIG. 13 is a schematic cross-sectional side view illustration of an electronic device in accordance with an embodiment.

DETAILED DESCRIPTION

[0022] Embodiments describe display modules and protective cover layer structures. In particular, embodiments describe protective cover layer structures that may be implemented in curved, flexible, conformable and foldable display modules, and in particular with curved, flexible, conformable and foldable display panels. Various embodiments are described in which a hardcoat layer is applied to a transparent support substrate to form a protective cover layer structure. The hardcoat layer may be characterized as possessing a lower elastic modulus, higher elongation-to-break and optionally a lower hardness than the transparent support substrate. In one aspect, such a hybrid structure may prevent

cracks from forming in the transparent support substrate. In another aspect, such a hybrid structure may move the neutral plane of protective cover layer so that the surfaces of the transparent support substrate see a lower strain upon bending.

[0023] In one aspect the formation of a hardcoat layer that is not as strong (lower elastic modulus) and not as tough (lower scratch resistance) as the transparent support substrate such as glass or sapphire is counterintuitive to traditional protective cover layers where the strongest and toughest materials are used for the outermost protective layer. The hardcoat layer in accordance with embodiments is still sufficiently strong and tough to provide sufficient scratch resistance and durability (e.g. after months of daily scratches) while also preventing cracking of the more brittle transparent support substrate.

[0024] In various embodiments, description is made with reference to figures. However, certain embodiments may be practiced without one or more of these specific details, or in combination with other known methods and configurations. In the following description, numerous specific details are set forth, such as specific configurations, dimensions and processes, etc., in order to provide a thorough understanding of the embodiments. In other instances, well-known processes and manufacturing techniques have not been described in particular detail in order to not unnecessarily obscure the embodiments. Reference throughout this specification to “one embodiment” means that a particular feature, structure, configuration, or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, the appearances of the phrase “in one embodiment” in various places throughout this specification are not necessarily referring to the same embodiment. Furthermore, the particular features, structures, configurations, or characteristics may be combined in any suitable manner in one or more embodiments.

[0025] The terms “over”, “to”, “between”, and “on” as used herein may refer to a relative position of one layer with respect to other layers. One layer “over”, or “on” another layer or bonded “to” or in “contact” with another layer may be directly in contact with the other layer or may have one or more intervening layers. One layer “between” layers may be directly in contact with the layers or may have one or more intervening layers.

[0026] Referring now to FIG. 1 a schematic isometric view illustration is provided of a protective cover layer **100** in accordance with an embodiment. As shown, the protective cover layer **100** may include a transparent support substrate **102** and a hardcoat layer **104** covering an exterior facing surface **103** of the transparent support substrate **102** when installed in an electronic device. In an embodiment, the transparent support substrate **102** is a glass substrate which may be formed of materials such as soda lime, borosilicate, fused silica, aluminosilicate, or any other thin glass material. The transparent support substrate **102** may also be formed of sapphire. The transparent support substrate may be a brittle material. The transparent support substrate may have a thickness less than 150 μm , such as 25 μm -125 μm .

[0027] The hardcoat layer **104** may be a hard material that has a lower elastic modulus and higher elongation-to-break than the transparent support substrate **102**. The hardcoat layer **104** may optionally be characterized by a hardness that is less than that of the transparent support substrate **102**. For example, the transparent support substrate **102** may have a

pencil hardness greater than 9 H, while the hardcoat layer **104** has a pencil hardness greater than 1 H. In an embodiment, the hardcoat layer **104** has an elastic modulus range of 40 GPa-400 GPa. Typical elastic modulus of glass is around 60-75 GPa, and can go as low as 45 GPa with a high concentration of alkali cations. Sapphire can have an elastic modulus as high as 370 GPa. The hardcoat layer may have a thickness range of 1 μm -200 μm , for example.

[0028] Generally, the hardcoat layer **104** may be more resilient than the transparent support substrate **102**. Referring to FIG. 2, a schematic cross-sectional side view illustration is provided of a bent protective cover layer **100** in accordance with an embodiment. Additionally illustrated are the neutral plane **202A** for strain without the hardcoat layer **104**, and the neutral plane **202B** for strain with the addition of the hardcoat layer **104**. As shown, addition of the hardcoat layer **104** can have the effect of shifting the neutral plane. This has the additional effect adjusting the high strain location. In the original configuration without the hardcoat layer **104**, the exterior facing surface **103** of the transparent support substrate **102** sees the highest tensile strain, while the interior facing surface **105** of the transparent support substrate **102** sees the highest compressive strain. Addition of the hardcoat layer **104** can have the effect of shifting the neutral plane **202B**, and lowering the tensile strain at the exterior facing surface **103** of the transparent support substrate **102** in the particular embodiment illustrated. Typically, glass fracture initiates from the presence of micro-cracks. The hardcoat layer **104** in accordance with embodiments may fill pre-existing micro-cracks and also make it harder to initiate a crack. Furthermore, the hardcoat layer **104** may be engineered to have a sufficiently high hardness and tensile strength to function as an exterior protective coating for the electronic device, while being able to withstand more strain before fracture compared to the transparent support substrate **102**. Thus, the hardcoat layer **104** is sufficiently durable for high puncture and scratch resistance.

[0029] The hardcoat layer **104** may be a polymer-based material, and may be filled. In an embodiment the hardcoat layer **104** has a silica acrylate polymer matrix. Other polymer materials such as epoxy may be used. The polymer matrix is optionally filled with ceramic particles such as Al_2O_3 , MgAlO_4 , SiAlON , AlON , ZrO_2 . Particle fillers may be sized and dispersed in a way to improve film strength, while not impacting optical properties of the film. The hardcoat layer **104** may have a refractive index matched with the transparent support substrate **102** or higher to aid in outcoupling of light. In an embodiment the hardcoat layer **104** is engineered to have a graded elastic modulus. For example, a high inorganic fraction can be included in the composition nearer the transparent support substrate **102** resulting in a glass-like modulus at the inner surface **109**, with the inorganic fraction reducing toward to the outer (exterior facing) surface **107** resulting in a reduced elastic modulus. In an embodiment, the hardcoat layer is characterized by a graded elastic modulus that is lower nearest the transparent support substrate **102** and higher nearest an outer surface **107** of the hardcoat layer. The hardcoat layer may include a particle filler within a polymer matrix, and a particle filler concentration is higher nearest the transparent support substrate **102** and lower nearest the outer surface

107 of the hardcoat layer. The hardcoat layer may also comprise a multilayer structure of materials with different modulus properties.

[0030] The hardcoat layer 104 may be applied using physical vapor deposition (CVD) or solution-based techniques such as slot coating, spray coating, dip coating, and sol-gel. The hardcoat layer 104 may be applied to a polished surface, or surfaces, of the transparent support substrate. In an embodiment, the hardcoat layer is on a surface (e.g. 103, 105) of the transparent support substrate 102 characterized by an area roughness (Ra) of 0.5 nm-10 nm, and an outer (exterior facing) surface 107 of the hardcoat layer 104 is characterized by a greater area roughness than the surface of the transparent support substrate on which the hardcoat layer is located.

[0031] In order to demonstrate effectiveness of the hardcoat layer 104, both simulation and physical scratch/bending tests were performed. FIG. 3 is a plot of simulated tensile strain at the transparent support substrate exterior facing surface 103 for different hardcoat layer thicknesses in accordance with embodiments, with an outward bending direction as illustrated in FIG. 2. As shown, in the simulated bending tests, application of a 25 μ m thick hardcoat layer 104 was simulated to reduce tensile strain at the exterior facing surface 103 of the transparent support substrate 102, with a 25 μ m thick hardcoat layer 104 further reducing tensile strain.

[0032] Referring now to FIGS. 4A-4B scratch/bending tests were performed on a baseline transparent support substrate 102 (FIG. 4A) and a hardcoat layer 104 coated transparent support substrate 102 (FIG. 4A). As shown in the schematic top view illustrations of the tests, steel wool was used to create crack sites 410 at the same locations of the transparent support substrate 102. In each case, the transparent support substrate 102 was a 70 μ m thick glass substrate. A 25 μ m thick silica acrylate polymer hardcoat layer 104 was formed over a portion of the exterior facing surface 103 of the transparent support substrate 102 for the test sample of FIG. 4B, including over the crack sites 410.

[0033] Bending tests were performed until failure (crack propagation) of both test samples. The baseline sample of FIG. 4A resulted in a minimum radius of 3.05 mm at failure (crack propagation). As illustrated, the crack 420 formation and propagation initiated at a crack site 410. The test sample of FIG. 4B resulted in a minimum radius of 2.60 mm at failure. Crack 420 formation and propagation did not initiate at a crack site 410, and instead formed and propagated from a non-scratch site outside of the hardcoat layer 104 coating area. As demonstrated, the hardcoat layer 104 appears to have provided a higher level of durability, and protected the pre-existing crack sites 410 from propagating as well as the formation and propagation of new crack sites where the hardcoat layer 104 was formed.

[0034] Thus far embodiments have been described in which a single hardcoat layer 104 is applied to a single side of a transparent support substrate 102. Increased durability under outward bending has been verified with simulation and physical testing. However, embodiments are not so limited. Multiple hardcoat layers 104 may be applied to multiple sides of the transparent support substrate 102, or a single hardcoat layer 104 may be applied to multiple sides of the transparent support substrate 102 or cover all surfaces of the transparent support substrate 102. Furthermore, the hardcoat layer(s) 104 may be designed to increase durability

for outward and/or inward bending. Additional layers may be applied between the hardcoat layer 104 and the transparent support substrate 102. Additionally, anti-smudge coating, such as an oleophobic coating may be applied to an external surface of the hardcoat layer 104. Preferably, the refractive index of the hardcoat is reasonably matched to the refractive index of the support substrate. In another embodiment, the hardcoat may serve as an antireflective layer for the display, comprising either a low refractive index material, or a multilayer structure providing antireflection properties.

[0035] FIG. 5A is a schematic cross-sectional isometric view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment. FIG. 5B is a schematic cross-sectional side view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment. As illustrated, a glass fiber mesh 106 may be located between the hardcoat layer 104 and the transparent support substrate 102. The glass fiber mesh 106 may function to catch fragments that break from the transparent support substrate 102, and reduce the potential for cracks to propagate from the transparent support substrate 102 into the hardcoat layer 104, and vice versa. Thus, the glass fiber mesh 106 may function to localize a fracture size. The refractive index of the glass fibers in the glass fiber mesh 106 may be matched with the refractive index of the hardcoat layer 104. For example the refractive indices may be within 1.45 to 1.75 based on a glass to sapphire range. In an embodiment, the hardcoat layer 104 impregnates the glass fiber mesh 106, for example, when applied using a solution-based technique.

[0036] FIG. 6A is a schematic cross-sectional isometric view illustration of a protective cover layer including an intermediate glass fiber mesh layer in accordance with an embodiment. FIG. 6B is a close-up schematic cross-sectional side view illustration of the protective cover layer of FIG. 6A including an intermediate glass fiber mesh layer in accordance with an embodiment. In the embodiment illustrated the hardcoat layer 104 may surround lateral edges of the glass fiber mesh 106. Such a configuration may contain the potential for particle generation by the glass fiber mesh 106, and provide additional area for adhesion of the hardcoat layer 104 to the transparent support substrate 102. Preferably, the hardcoat layer is reasonably matched in refractive index to the glass mesh.

[0037] FIG. 7 is a schematic cross-sectional side view illustration of a protective cover layer 100 including a hardcoat layer 104 surrounding a transparent support substrate 102 in accordance with an embodiment. In an embodiment, the hardcoat layer 104 is formed on both the exterior facing surface 103 and an opposite interior facing surface 105 of the transparent support substrate 102. In an embodiment, the hardcoat layer 104 wraps around one or more lateral edges 101 of the transparent support substrate 102. Referring to FIG. 8, in an embodiment, the one or more lateral edges 101 of the transparent support substrate 102 may be tapered. Thickness of the hardcoat layer(s) 104 may be different on the exterior facing surface 103 and the interior facing surface 105 of the transparent support substrate 102 depending upon application. For example, for an outward bending application, the hardcoat layer 104 may be thicker on the exterior facing surface 103, while the hardcoat layer 104 may be thicker on the interior facing surface 105

for an inward bending application. In embodiment, the hardcoat layer **104** is only applied on the interior facing surface **105** (not the exterior facing surface **103**) for an inward bending application.

[0038] FIG. 9 is a schematic cross-sectional view illustration of a protective cover layer **100** including an intermediate polymer adhesion layer **108** in accordance with an embodiment. In an embodiment, the polymer adhesion layer **108** is located between the hardcoat layer **104** and the transparent support substrate **102**. The polymer adhesion layer may be 1-5 μm thick, for example. The polymer adhesion layer **108** may be optically transparent and may function to promote adhesion of the hardcoat layer **104**, which may have greater adhesion to the polymer adhesion layer **108** than to the material forming the transparent support substrate **102**. In the embodiment illustrated in FIG. 10, the polymer adhesion layer **108** may surround the transparent support substrate **102**. The hardcoat layer **104** may also surround the polymer adhesion layer **108**. Referring to FIG. 11, in an embodiment, the one or more lateral edges **101** of the transparent support substrate **102** may be tapered.

[0039] Referring now to FIGS. 12A-12B schematic isometric view illustrations of an electronic device **1200** are provided in accordance with embodiments. FIGS. 13 is a schematic cross-sectional side view illustration of an electronic device **1200** in accordance with an embodiment. In particular, the electronic device **1200** includes a display panel **150** and protective cover layer **100** over the display panel **150**. The protective cover layer **100** may be any of the protective cover layers **100** described herein. The display panel **150** and protective cover layer **100** may be curved, flexible, conformable and/or foldable. FIG. 12A illustrates an outward bending application, while FIG. 12B illustrates an inward bending application. In an embodiment, the display panel **150** and protective cover layer **100** are capable of both outward and inward bending. In an embodiment, the protective cover layer **100** flexes with the flexible display panel **150** and includes a transparent support substrate **102** and a hardcoat layer **104** covering an exterior facing surface **103** of the transparent support substrate **102**. In an embodiment, the flexible display panel is foldable, and the protective cover layer folds with the foldable display panel.

[0040] Referring to FIG. 13, in an embodiment, the hardcoat layer **104** of the protective cover layer **100** may define an exterior surface of the electronic device **1200**. For example, the outer (exterior facing) surface **107** may define the exterior surface of the electronic device **1200**. In an embodiment and anti-smudge coating, such as an oleophobic coating may be applied to an external surface of the hardcoat layer **104**. In an embodiment, a touch screen is located between the display panel **150** and the protective cover layer **100**. A space **1250** may be included in the electronic device **1200** housing **1210** to group various components such as a processor, memory, battery, wireless transceiver/receiver etc. for operation of the electronic device. As shown in FIGS. 12A-12B, housing **1210** may additionally include openings for controls **1220**, port **1230**, etc.

[0041] In utilizing the various aspects of the embodiments, it would become apparent to one skilled in the art that combinations or variations of the above embodiments are possible for forming a curved, flexible, and/or conformable display with protective cover layer. Embodiments may be

implemented in a variety of electronic devices including non-portable and portable devices, including wearable devices. Exemplary electronic devices include a communication device (e.g., mobile phone, smart phone, smart watch, wearable device), a multi-media device (e.g., MP3 player, TV, radio), a portable or handheld computer (e.g., tablet, netbook, laptop), a desktop computer, an All-In-One desktop, a peripheral device, a television, or any other system or device adaptable to the inclusion of a protective cover layer in accordance with embodiments. Although the embodiments have been described in language specific to structural features and/or methodological acts, it is to be understood that the appended claims are not necessarily limited to the specific features or acts described. The specific features and acts disclosed are instead to be understood as embodiments of the claims useful for illustration.

What is claimed is:

1. An electronic device comprising:
 - a display panel; and
 - a protective cover layer over the display panel, wherein the protective cover layer includes a transparent support substrate and a hardcoat layer covering an exterior facing surface of the transparent support substrate.
2. The electronic device of claim 1, wherein the hardcoat layer defines an exterior surface of the electronic device.
3. The electronic device of claim 1, further comprising a touch screen between the display panel and the protective cover.
4. The electronic device of claim 1, wherein the hardcoat layer is characterized by a lower elastic modulus than the transparent support substrate.
5. The electronic device of claim 4, wherein the hardcoat layer has a thickness range of 1-200 μm and the transparent support substrate has a thickness less than 150 μm .
6. The electronic device of claim 4, wherein the hardcoat layer has an elastic modulus range of 1 GPa-100 GPa.
7. The electronic device of claim 4, wherein the hardcoat layer includes a polymer matrix.
8. The electronic device of claim 7, wherein the polymer matrix is a silica acrylate polymer.
9. The electronic device of claim 7, wherein the hardcoat layer is characterized by a graded elastic modulus that is lower nearest the transparent support substrate and higher nearest an outer surface of the hardcoat layer.
10. The electronic device of claim 9, wherein the hardcoat layer includes a particle filler within the polymer matrix, and a particle filler concentration is higher nearest the transparent support substrate and lower nearest the outer surface of the hardcoat layer.
11. The electronic device of claim 4, wherein the hardcoat layer is on a surface of the transparent support substrate characterized by an area roughness (Ra) of 0.5 nm-10 nm, and an exterior facing surface of the hardcoat layer is characterized by a greater area roughness than the surface of the transparent support substrate on which the hardcoat layer is located.
12. The electronic device of claim 4, wherein the hardcoat layer is formed on both the exterior facing surface and an opposite interior facing surface of the transparent support substrate.
13. The electronic device of claim 12, wherein the hardcoat layer wraps around one or more lateral edges of the transparent support substrate.

14. The electronic device of claim **13**, wherein the one or more lateral edges of the transparent support substrate are tapered.

15. The electronic device of claim **4**, further comprising a polymer adhesion layer between the hardcoat layer and the transparent support substrate.

16. The electronic device of claim **15**, wherein the polymer adhesion layer is 1-10 μm thick.

17. The electronic device of claim **4**, further comprising a glass fiber mesh between the hardcoat layer and the transparent support substrate.

18. The electronic device of claim **4**, wherein the hardcoat layer is formed around lateral edges of the transparent support substrate.

19. The electronic device of claim **4**, wherein the transparent support substrate is formed of a material selected from the group consisting of glass and sapphire.

20. The electronic device of claim **4**, further comprising a smudge resistant coating on an exterior facing coating of the hardcoat layer.

21. An electronic device comprising:

a flexible display panel; and

a protective cover layer over the display panel, wherein the protective cover layer flexes with the flexible display panel and includes a transparent support substrate and a hardcoat layer covering an exterior facing surface of the transparent support substrate; and

a housing to contain the flexible display panel and the protective cover layer.

22. The electronic device of claim **21**, wherein the flexible display panel is foldable, and the protective cover layer folds with the foldable display panel.

* * * * *